Electron Beam Diagnostics with Libera

Using EPICS to monitor the electron beam position over timescales from 100 ns to hours.

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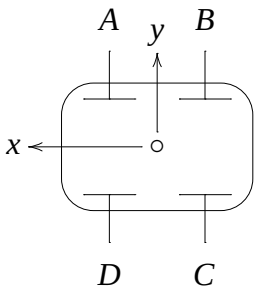
Diamond Light Source

Electron Beam Position Monitoring



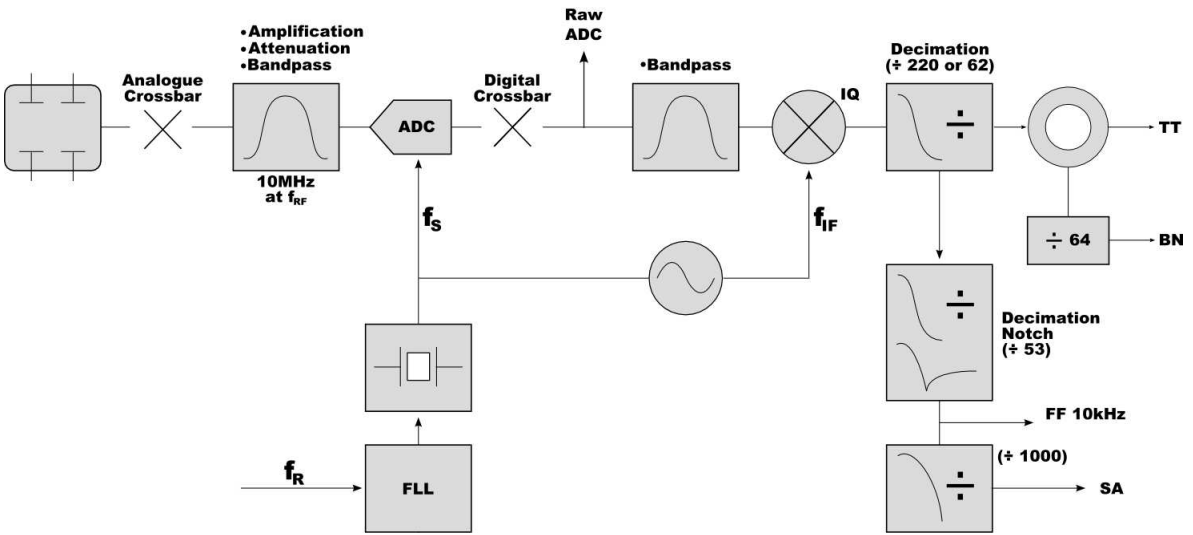
$$X = K_X \frac{A-B-C+D}{A+B+C+D} + X_0$$

$$Y = K_Y \frac{A+B-C-D}{A+B+C+D} + Y_0$$

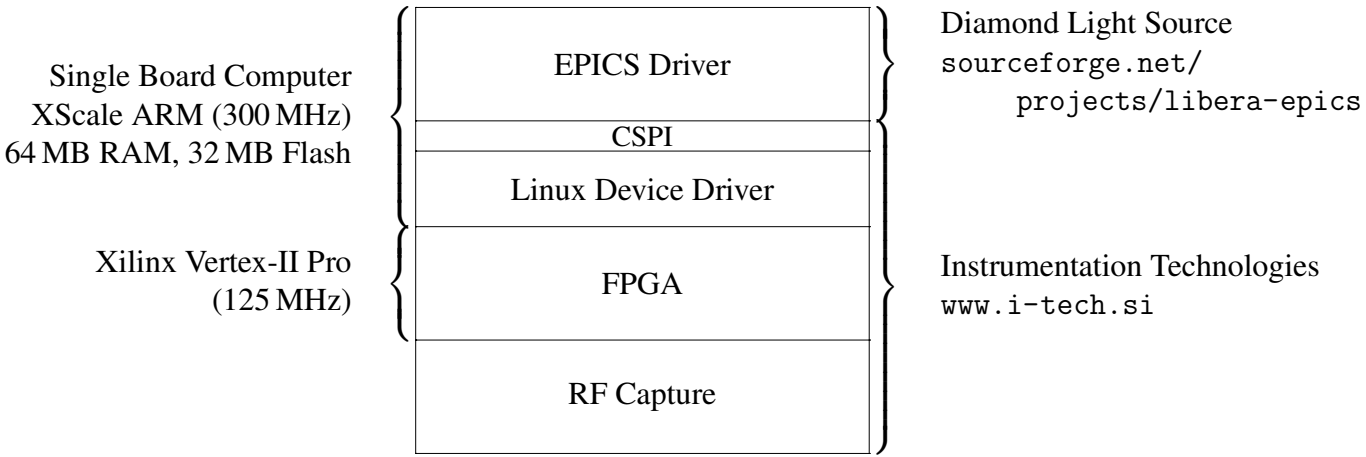
$$S = A+B+C+D \ .$$

- Electron beam monitored by pickups (buttons or striplines) above, below and to the sides.
- Electrical signal (modulated 500 MHz machine RF) received by each pickup.
- Strength of signal increases as beam approaches pickup.
- Linear "sum of differences" a good approximation for position when movement is small; normalise by beam intensity S.
- Small beam movements correspond to very small differences in signal intensity: sensitive electronics required!

Overview of Electronics



Libera System Architecture



Notes on Implementation

- EPICS driver implemented for EPICS 3.14 under Linux on an XScale ARM processor.
- Patch to EPICS channel access required for support: patches for .6, .7 and .8.2 in `libera-epics` distribution: strange "mixed endian" floating point format for doubles required. Hope to include in .9 release.
- XScale ARM does not have hardware floating point support: need to take care not to rely on fast floating point!
- Special implementation of two operations:
  - Magnitude of complex value

    $$|x+iy| = \sqrt{x^2+y^2}$$

    implemented using CORDIC algorithm: 135 ns per point!
  - Approximate division (24 bits accuracy) implemented using lookup and linear approximation.

  Efficient implementations of these two operations allow high volumes of turn-by-turn data to be handled.

Output Formats

Raw ADC Each button is sampled at 117 MHz, machine RF f_{RF} (500 MHz) undersampled as $f_{IF} \approx 32$ MHz

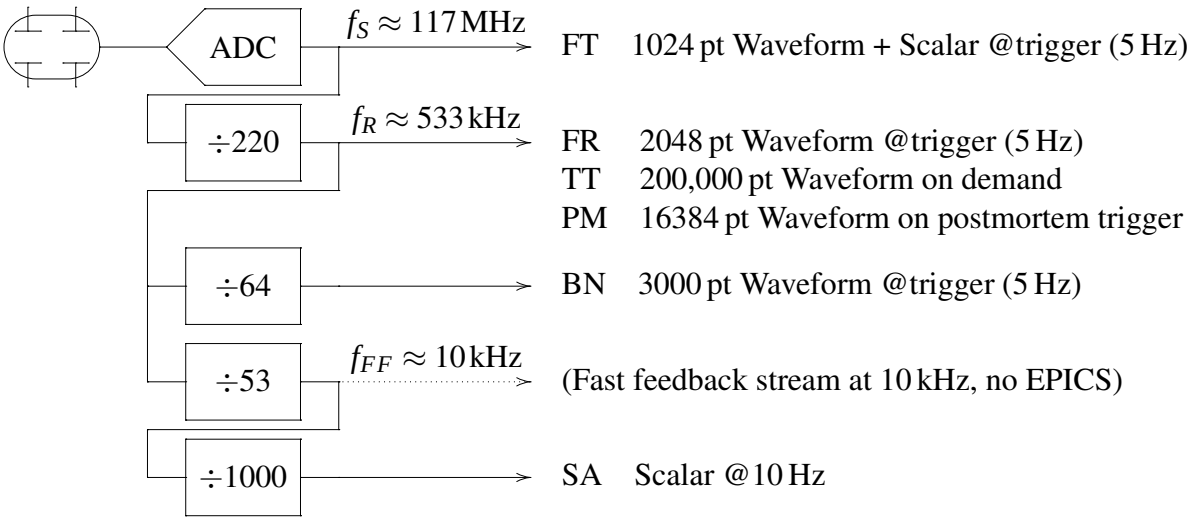
IQ streams For each button the raw stream is mixed with f_{IF} *in quadrature*: i.e., we multiply by $\exp(2\pi i f_{IF} t)$, to produce a slowly rotating complex number $A_I + iA_Q$ (and similarly for B, C, D). These streams are then low pass filtered.

Button Intensities The button intensity is recovered, after filtering, as the magnitude of the IQ value, ie $A = |A_I + iA_Q| = \sqrt{A_I^2 + A_Q^2}$.

Positions and Beam Intensity X, Y and S are calculated as shown on the first slide.

All of these data streams are provided through EPICS.

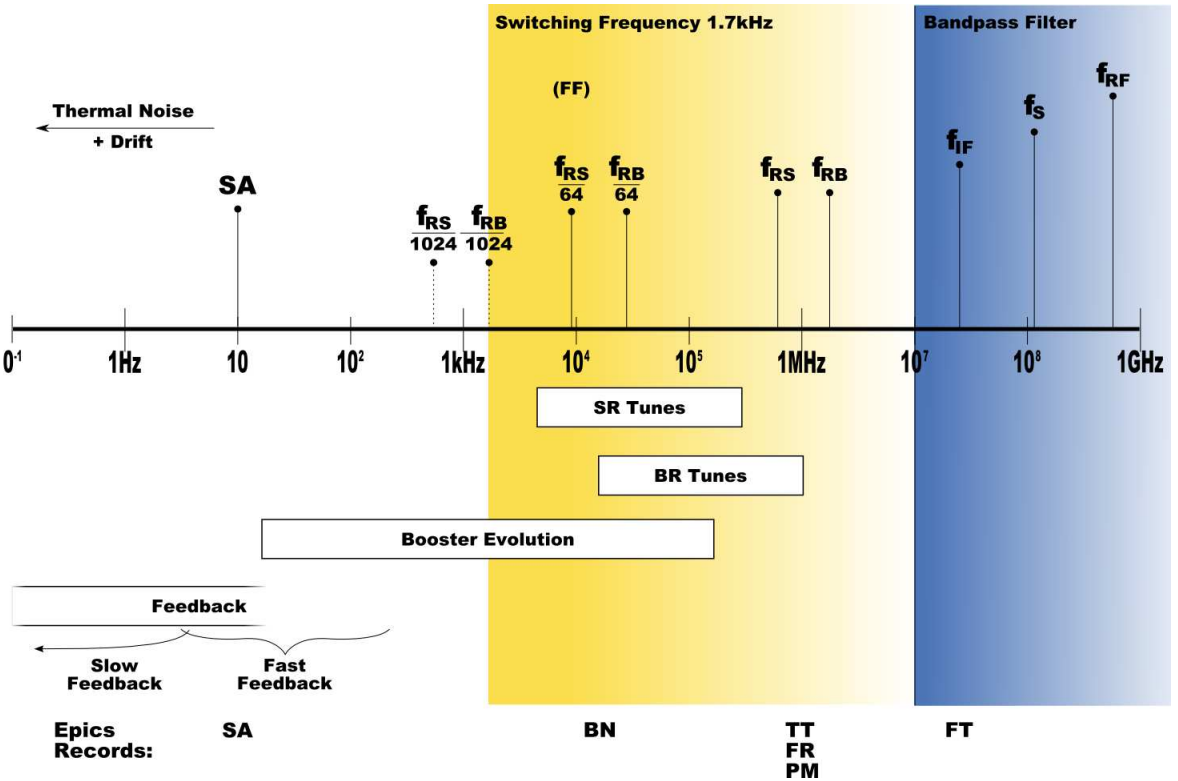
Libera Processing and Outputs



Overview of processing chain within Libera and the generated EPICS outputs.

FT	First Turn
FR	"Free Running": continuously updating at turn-by-turn frequency
TT	Long Turn by Turn data, only triggered on demand
BN	Decimated data, designed for booster overview
SA	Slow Acquisition

Spectral Coverage of Libera



EPICS Outputs

FT First Turn. Allows the position of a single train of bunches to be measured. This allows individual turns to be measured.

FR 2048 points at turn by turn frequency, updated on every trigger.

TT Potentially up to 1 second's worth of turn by turn data, captured on a trigger. Used to monitor tune evolution, in particular during booster ramp.

BN Decimated data, used for booster ramp monitoring and closed orbit determination. Both TT $\div 64$ and $\div 1024$ provided as waveforms.

SA Slow acquisition, long term monitoring of stored beam position, and usable for slow feedback.

PM Postmortem, to be triggered on beam loss.

Should also mention:

FF Fast feedback. Not planned for EPICS access.

Libera at Diamond

We have 204 Liberas installed:

7 in Linac to Booster transfer

22 in Booster

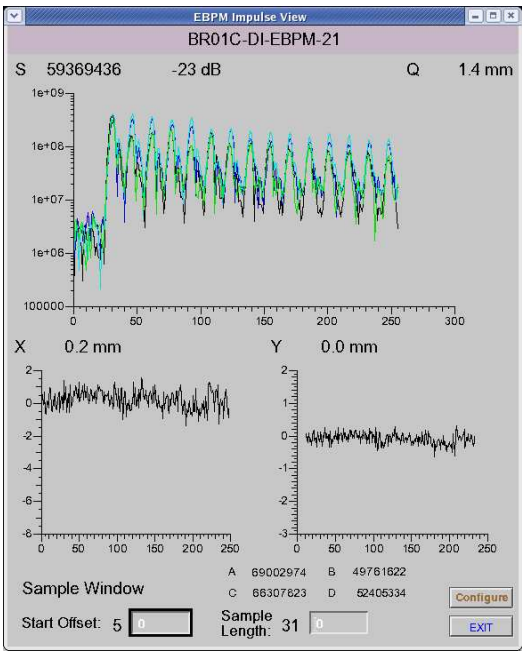
7 in Booster to Storage transfer

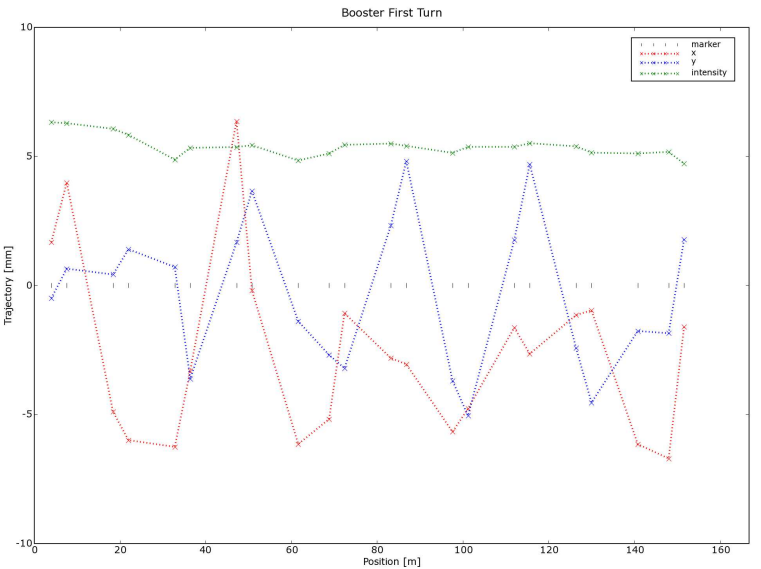
168 (24×7) in Storage ring

Used for:

- Threading beam around the ring
- Manual orbit correction
- Response matrix measurement
- Tune measurement and tracking

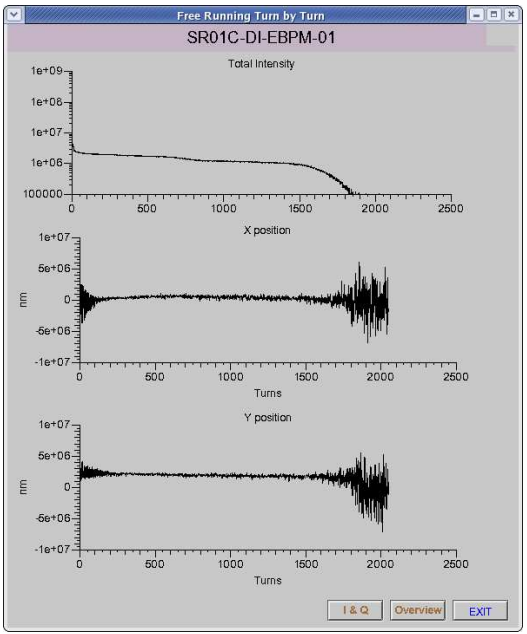
First Turn

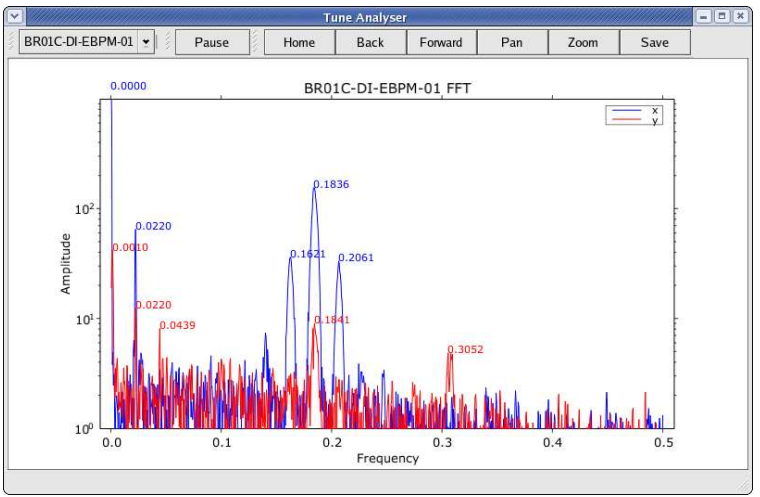




First turns in the booster.

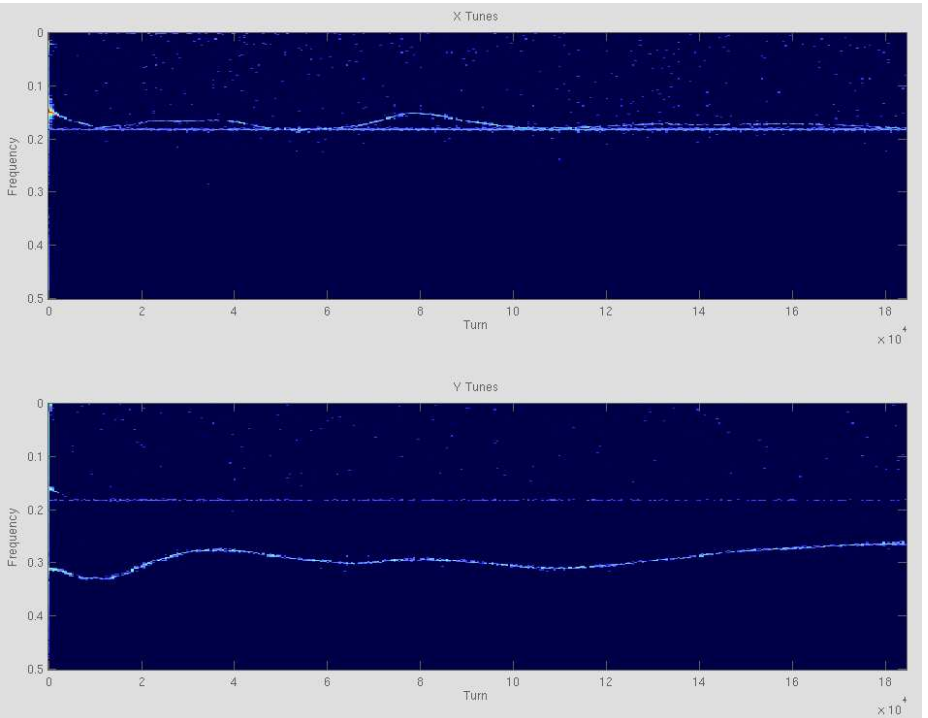
Free Running Turn by Turn





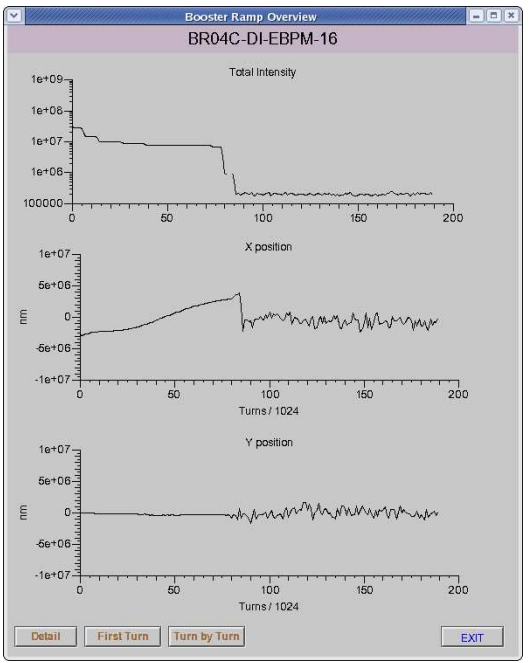
First 2048 turns and tune spectrum, calculated on every trigger.

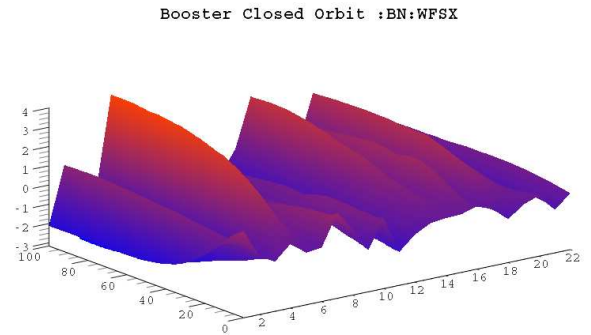
Long Waveform Turn by Turn

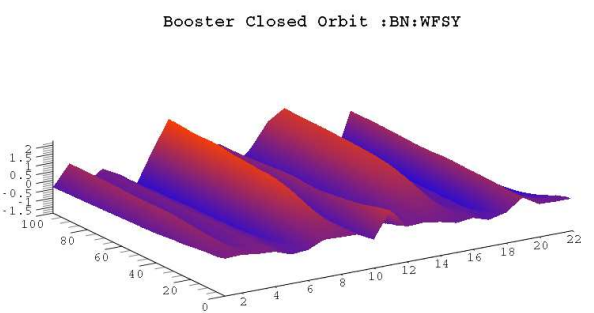


Tune evolution over a single booster ramp.

Booster Ramp: Decimated Data

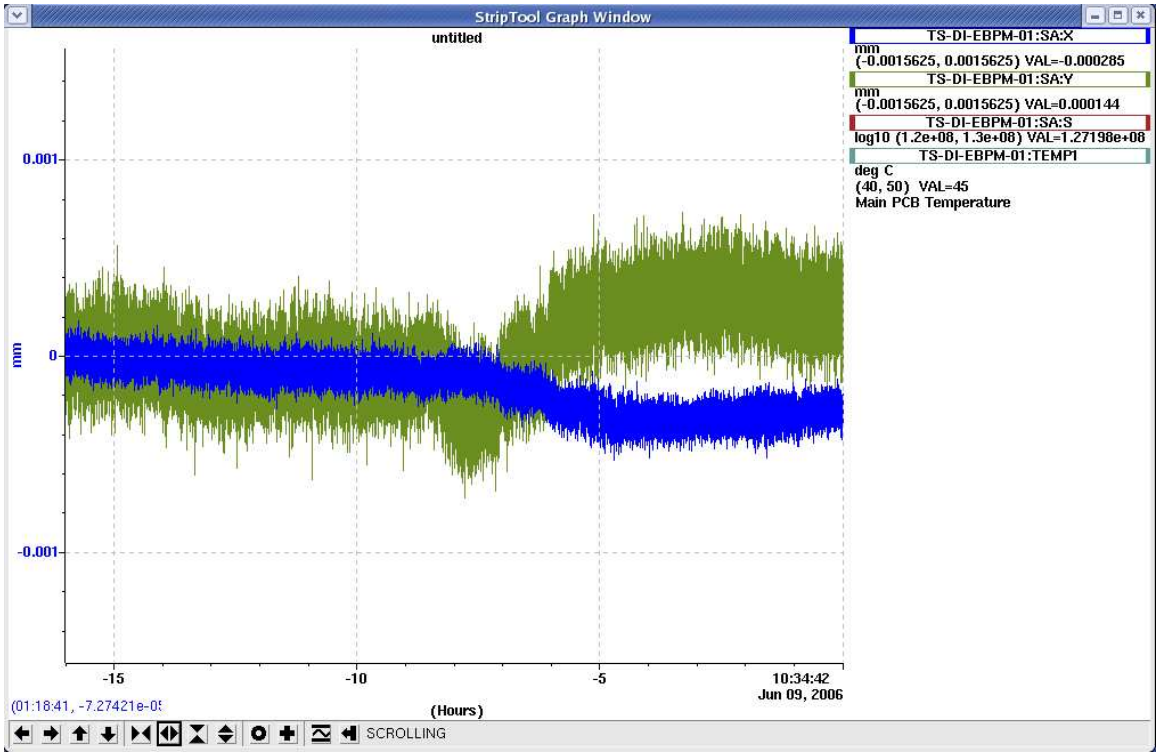






Evolution of booster orbit during ramp.

Slow Acquisition



Slow acquisition (10 Hz) over 16 hours: $\pm 1\,\mu m$ full scale!